September 2006

Hydro Plant Risk Assessment Guide

Appendix E3: Governor Condition Assessment

E3.1 GENERAL

Speed governors are major elements of hydroelectric generating units and are appropriate for analysis under a condition assessment program. Unexpected governor failure can have a significant economic impact due to lost revenues during an extended forced outage.

Determining the present condition of a speed governor is an essential step in analyzing the risk of failure. This appendix provides a process for arriving at a Governor Condition Index which may be used to develop a business case addressing risk of failure, economic consequences, and other factors.

E3.2 SCOPE / APPLICATION

The governor condition assessment methodology outlined in this appendix applies to mechanical, analog, and digital speed governors. This appendix primarily focuses on the governor control system and the governor valves. The components listed below are within the scope of this document.

1. Governor Control System (mechanical, analog or digital)

   - Speed sensing devices
   - Speed adjustment
   - Speed droop
   - SSG (speed signal generator) or PMG (permanent magnet generator)
   - Restoring mechanism
   - Pilot valve

2. Governor Distributing Valves & Auxiliary Valve (if applicable)

Servomotors and other auxiliary components such as pressure and sump tanks, pumps, oil filters, piping and hydraulic valves (other than the governor valves) are not considered during this assessment.

This appendix is intended for application to each individual governor at a plant and not to an entire plant or to a family of governors at a plant. Each governor should be evaluated separately for condition rating and prioritizing investment needs.

This appendix is not intended to define governor maintenance practices or describe in detail governor inspections, tests or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

E3.3 CONDITION AND DATA QUALITY INDICATORS AND GOVERNOR CONDITION INDEX

This appendix describes the condition indicators generally regarded by hydro plant engineers as providing the initial basis for assessing governor condition.

The condition assessment methodology consists of analyzing each condition indicator individually to arrive at a condition indicator score. The scores are weighted and summed to determine the Condition Index.

An additional stand-alone indicator is used to reflect the quality of the information available for scoring the governor condition indicators. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the validity of the overall Condition Index. Given the potential impact of poor or missing data, the Data Quality Indicator is used as a means of evaluating and recording confidence in the final Governor Condition Index.

Additional information regarding governor condition may be necessary to improve the accuracy and reliability of the Governor Condition Index. Therefore, in addition to the Tier 1 condition indicators, this appendix describes a "toolbox" of Tier 2 inspections, tests, and measurements that may be applied to the Governor Condition Index, depending on the specific issue or problem being addressed. Tier 2 tests are considered non-routine. However, if Tier 2 data is readily available, it may be used to supplement the Tier 1 assessment. Alternatively, Tier 2 tests may be deliberately performed to address Tier 1 findings. Results of the Tier 2 analysis may either increase or decrease the score of the Governor Condition Index. The Data Quality Indicator score may also be revised during the Tier 2 assessment to reflect the availability of additional information or test data.

The Governor Condition Index is applied to the Governor Condition-Based Alternatives Table (Table 9) to determine the recommended course of action. The Governor Condition Index may indicate the need for immediate corrective actions and/or follow-up Tier 2 testing. The Governor Condition Index is also suitable for use as an input to the risk-based economic analysis model.

Note: A severely negative result of ANY inspection, test, or measurement may be adequate in itself to require immediate de-energization or prevent re-energization of the governor, regardless of the Governor Condition Index score.

E3.4 INSPECTIONS, TESTS, AND MEASUREMENTS

Inspections, tests and measurements should be conducted and analyzed by staff suitably trained and experienced in governor diagnostics. More complex inspections and measurements may require an expert.

Inspections, tests, and measurements should be performed on a frequency that provides the accurate and current information needed by the assessment.

Details of the inspection, testing, and measurement methods and intervals are described in technical references specific to the electric utility.

E3.5 SCORING

Condition indicator scoring is somewhat subjective, relying on the experience and opinions of competent personnel. Relative terms such as “Results Normal” and “Degradation” refer to results that are compared to industry-accepted levels; or to baseline or previously acceptable levels on this equipment; or to equipment of similar design, construction, or age operating in a similar environment.

E3.6 WEIGHTING FACTORS

Weighting factors used in the condition assessment methodology recognize that some condition indicators affect the Governor Condition Index to a greater or lesser degree than other indicators. These weighting factors were arrived at by consensus among governor maintenance and engineering personnel with extensive experience.

E3.7 MITIGATING FACTORS

Every governor is unique and, therefore, the methodology described in this guide cannot quantify all factors that affect individual governor condition. If the Condition Index triggers significant follow-up actions (e.g., major repairs or a Tier 2 assessment), it may be prudent to first have the index reviewed by governor experts. Mitigating factors specific to the utility may affect the final Condition Index and the final decision on replacement or rehabilitation.

E3.8 DOCUMENTATION

Substantiating documentation is essential to support findings of the assessment, particularly where a Tier 1 Condition Indicator score is less than 3 (i.e., Normal) or where a Tier 2 analysis results in subtractions to the Governor Condition Index. Test reports, facility review reports, special exams, photographs, O & M records, and other documentation should accompany the Governor Condition Assessment Summary form.

E3.9 CONDITION ASSESSMENT METHODOLOGY

The condition assessment methodology consists of analyzing each condition indicator individually to arrive at a condition indicator score. The scores are weighted and summed to determine the Condition Index.

Reasonable efforts should be made to perform Tier 1 inspections, tests, and measurements. However, when data is unavailable to properly score the Condition Indicator, it may be assumed that the score is "Good" or numerically equal to some mid-range number such as 2. This strategy must be used judiciously to prevent erroneous results and conclusions. In recognition of the potential impact of poor or missing data, a separate Data Quality Indicator is rated during the Tier 1 assessment as a means of evaluating and recording confidence in the final Governor Condition Index.

E3.10 TIER 1 – GOVERNOR INSPECTIONS, TESTS, AND MEASUREMENTS

The following condition indicators are used to perform a Tier 1 Condition Assessment:

- Age
- Operation and Maintenance History
- Availability of Spare Parts
- Performance

The Tier 1 condition indicators are based on inspections, tests, and measurements conducted by utility staff over the course of time and as a part of routine maintenance activities. Numerical scores are assigned to each Tier 1 condition indicator, which are then weighted and summed to determine the Governor Condition Index.

Governor Condition Indicator 1 – Age

The age of the governor is among the factors to consider when identifying candidates for mechanical rehabilitation, partial replacement (digital retrofit), or complete replacement. Age is one indicator of remaining life and upgrade potential to current state-of-the-art materials and designs.

As a governor ages, the mechanical parts become affected by wear and are more susceptible to internal leaks, thus affecting its performance. In the same way, the electronic parts are subjected to more deterioration due to overheating, excessive vibration, or contamination.

Although actual service life varies depending on the manufacturer's design, quality of assembly, materials used, and operation and maintenance history, the average expected life for a governor is most dependent on the technology used (mechanical, analog, or digital). Statistically, the average service life for a governor control system varies from 15 to 40 years depending upon the type of control system.

The following tables are used to separately evaluate the age of mechanical, analog and digital governors. Depending on the governor type, apply the Governor Age to Table 1A, 1B, or 1C, whichever is appropriate.

Table 1 – Age Scoring Control System

Table 1A – Age Scoring Mechanical Control System	
Age	**Condition Indicator Score**
< 25 years	3
≥ 25 and < 40 years	2
≥ 40 years	1

Table 1B – Age Scoring Analog Control System	
Age	**Condition Indicator Score**
< 20 years	3
≥ 20 and < 30 years	2
≥ 30 years	1

Table 1C – Age Scoring Digital Control System	
Age	**Condition Indicator Score**
< 10 years	3
≥ 10 and < 15 years	2
≥ 15 years	1

Condition Indicator 2 – Operation & Maintenance History

Operation and maintenance (O & M) history provides useful information for determining the governor condition. Records should be examined to evaluate the amount of maintenance carried out in the past to keep the governor in operation and in good condition. The amount of preventive and corrective maintenance required and the occurrence of operational limitations play a role in determining the condition and reliability of a governor, and the need for capital investment.

O & M history is reviewed and results are applied to Table 2 to arrive at an appropriate condition indicator score.

Table 2 – Operation & Maintenance History Scoring

Historical Results	Condition Indicator Score
Normal preventive and corrective maintenance (< 50 hours/year/unit) or no significant increase in preventive and corrective maintenance (less than 1.5 x baseline, as established by maintenance records).	3
Significant increase (over 1.5 x baseline) in preventive maintenance, but no significant increase in corrective maintenance, or operational constraints occurring rarely.	2
Significant increase (over 1.5 x baseline) in corrective maintenance or operational constraints occurring occasionally.	1
Repeated corrective maintenance or operational constraints.	0

Condition Indicator 3 – Availability of Spare Parts

Availability of spare parts is an important factor to take into account when determining the need for upgrade and the serviceability of governors. Consideration shall be given only to wear parts or parts that can be reasonably expected to require future replacement or rehabilitation. This condition indicator is applicable to mechanical parts as well as electronic parts.
The assessment of spare parts availability is applied to Table 3 to arrive at an appropriate condition indicator score.

Table 3 – Availability of Spare Parts Scoring

Availability	Condition Indicator Score
All necessary mechanical and electronic parts are available from original supplier.	3
Necessary mechanical and electronic parts are no longer available from original supplier and must be obtained from alternate suppliers.	2
Some electronic and mechanical parts are not available at all and/or some mechanical parts must be reverse-engineered and manufactured by alternate suppliers.	1
Most mechanical and electronic parts are not available at all and/or there are significant obstacles to successful reverse-engineering of mechanical parts.	0

Condition Indicator 4 – Performance

The performance of a speed governor is one of the leading indicators in determining its condition. Factors to consider in evaluating the performance may include:

- Synchronization time and ability;
- System stability;
- Black start capability (if applicable);
- Auto-synchronization capability (if applicable);
- Ability to remote start (if applicable);
- Accuracy and repeatability in response to load change and system disturbance;
- Hunting problems.

Governor performance is analyzed and the results are applied to Table 4 to arrive at an appropriate condition indicator score.

Table 4 – Performance Scoring

Observations (Criteria)	Condition Indicator Score
Off-line and on-line response and stability normal, governor free from hunting, accuracy of frequency within < 0.2 Hz, synchronization time within the norm, and able to remote start.	3
Off-line and on-line response and stability are fair, occasional hunting problems, synchronization time and accuracy of frequency outside the norm, or remote start is difficult.	2
Poor off-line and on-line response and stability, re-occurring hunting problems, difficulty in synchronization, or unable to remote start.	1

A score of 3 should be given if all corresponding criteria are met. A score of 1 or 2 should be given if at least one of the corresponding situations occurs.

E3.11 TIER 1 – GOVERNOR CONDITION INDEX CALCULATIONS

Enter the condition indicator scores from the tables above into the Governor Condition Assessment Summary form at the end of this document. Multiply each indicator score by its respective Weighting Factor, and sum the Total Scores to arrive at the Tier 1 Governor Condition Index. This index may be adjusted by the Tier 2 governor inspections, tests, and measurements described in section E3.13 of this document. Suggested alternatives for follow-up action based on the Governor Condition Index are described in the Governor Condition-Based Alternatives table (Table 9).

E3.12 GOVERNOR DATA QUALITY INDICATOR

The Governor Data Quality Indicator reflects the quality of the inspection, test, and measurement results used to evaluate the governor condition under Tier 1. The more current and complete the results are, the higher the rating for this indicator. The normal testing frequency is defined as the organization's recommended frequency for performing the specific test or inspection.

Qualified personnel should make a determination of scoring that encompasses as many factors as possible under this indicator. Results are analyzed and applied to Table 5 to arrive at an appropriate Governor Data Quality Indicator Score.

Table 5 – Data Quality Scoring

Results	Data Quality Indicator Score
All Tier 1 inspections, tests, and measurements were completed within the normal testing frequency and results are reliable.	10
One or more of the Tier 1 inspections, tests, and measurements were completed ≥ 6 and < 24 months past the normal testing interval and results are reliable.	7
One or more of the Tier 1 inspections, tests, and measurements were completed ≥ 24 and < 36 months past the normal testing interval, or some of the results are not available or are of questionable integrity.	4
One or more of the Tier 1 inspections, tests, and measurements were completed ≥ 36 months past the normal interval or many results are of questionable integrity or no results are available.	0

Enter the Governor Data Quality Indicator Score from Table 5 into the Governor Condition Assessment Summary form at the end of this document.

E3.13 TIER 2 – GOVERNOR INSPECTIONS, TESTS, AND MEASUREMENTS

The following condition indicators are used to perform a Tier 2 Condition Assessment:

- Leakage Test
- Step Response Test
- Physical Inspection

The Tier 2 condition indicators are based on selected appropriate inspections, tests, and measurements conducted by qualified personnel or experts and as a part of non-routine maintenance activities. Numerical scores are assigned to each Tier 2 condition indicator, which are used to adjust the Governor Condition Index determined in Tier 1, to arrive at a Revised Condition Index.

Test T2.1: Leakage Test

The rate of oil leakage is indicative of the condition of the valves in the governor system. The leakage test can determine the consumption of the main valve and the auxiliary valve. The consumption of the pilot valve is considered too small to show significant data.

1. The following test shows the leakage of the main valves:

   Prior to doing this test:

   - Scroll case must be empty;
   - Main valve should be blocked in its hydraulic centered position (this position is achieved when the pressure is equal on each side of the servomotor piston or when there is no movement of the servomotor);
   - Vibrator motor should be isolated by closing the appropriate valve;
   - Pilot valve should be isolated from incoming oil by closing the appropriate valve;
   - Auxiliary valve should be closed (the transfer valve is on the main valve).

   The consumption of the main valve can be determined by the leakage rate read on the tank. For better accuracy, take a large change in oil (ΔH) or use computerized instrumentation.

   For a Kaplan runner, this test will provide the leakage of the two main valves combined. The piston of the runner must be isolated.

2. The following test shows the leakage of the auxiliary valve (if applicable):

   Prior to doing this test:

   - Scroll case must be empty;
   - Gates must be moved to 50 % opening (this position is achieved when the pressure is equal on each side of the servomotor piston);
   - Vibrator motor should be isolated by closing the appropriate valve;
   - Pilot valve should be isolated from incoming oil by closing the appropriate valve;
   - Main valve should be closed (the transfer valve in on the auxiliary valve).

   The consumption of the auxiliary valve can be determined by the leakage rate read on the tank. For better accuracy, take a large change in oil level (ΔH) or use computerized instrumentation.

$$Leakage\ rate = \frac{\Delta H \times \pi d^2}{T} \times 6.493 \times 10^{-2} \left[US\ gal / \min\right]$$

where

ΔH = change in oil level [inches]
d = diameter of the tank [inches]
T = time [seconds]

Overall Leakage = Leakage from the main valves (including main valve for Kaplan runner)
+ Leakage from the auxiliary valve

Table 6 – Overall Leakage Rate Scoring

Observations (Criteria)	Adjustment to Condition Index Score
No significant increase on leakage rate from original value or previous data or that of comparable governors.	No change
Small increase in the leakage rate.	Subtract 1.0
Leakage rate has doubled (or more).	Subtract 2.0

Test T2.2: Step Response Test

In order to adequately evaluate a governor's performance, its various settings (such as needle valve, compensating crank, restoring ratio on a mechanical governor) must be adjusted to their optimum values, given the current condition of the governor. A poorly performing governor may not be in bad condition, but just misadjusted. The various settings must be set to match the response of the governor to the rotating inertia of the generator and the inertia of the water column in the penstock. A properly adjusted governor in good condition will be able to maintain off-line speed stability within < 0.2 Hertz, allow the unit to be synchronized to the bus, allow the unit to be quickly loaded when operating on an infinite bus, and will be able to maintain frequency within < 0.2 Hertz when operating isolated. Making adjustments to simply reduce off-line hunting to make it easier to synchronize on-line many times will make the governor unresponsive on-line or unable to react quickly enough to maintain frequency if the unit should become isolated. Procedures for these adjustments for mechanical governors are found in Reclamations FIST Volume 2-3, Mechanical Governors for Hydroelectric Units. These procedures take into account the penstock geometry and rotating mass of the generator. If an optimum response can not be accomplished, major work or replacement of the governor may be required.

Dead time and friction will be evident when performing the step response test. It can induce a significant time lag in the response. Any lag in movement from the time a step in speed set point is initiated and actual movement of the gates occurs is referred to as dead time and is usually a result of friction in the governor, restoring cable, in the servomotor, or wicket gate linkage. The response to a small (0.5 to 1%) speed changer step should be a smooth, regular curve. If the response shows any erratic movement, friction is likely someplace in the turbine control system. Likely places in the governor for friction are the dashpot, linkage pins and bearings, pilot valve and main valve. The motion of the main valve should also be observed during a step response. The motion of the dither of around 6 to 9 mils should always be evident. The motion following a speed step should be a quick initial movement and then a smooth movement back to center. Erratic movement during the step, or when at a steady state condition, usually indicates some problem with the main or pilot valves.

After making required adjustments as described above, a step response test may be performed. This test will normally be performed off-line by inputting a speed step, but may be performed on-line by inputting a load step. The governor is evaluated by inputting a speed or frequency (or load) step of 1% minimum and 5% maximum and recording the response in speed (and/or load) versus time. For mechanical governors, it is acceptable to make the test easier by inputting the step with a sudden change of the speed adjust.

It is preferred to compare the governor response to a computer simulation model of the governor. In the absence of a computer simulation, it is acceptable to compare the response to the typically recommended 0.7 critically damped system. The response should be similar to the response shown in Figure 1 for off-line testing. For on-line testing with a load step a response with higher damping and no overshoot is expected.

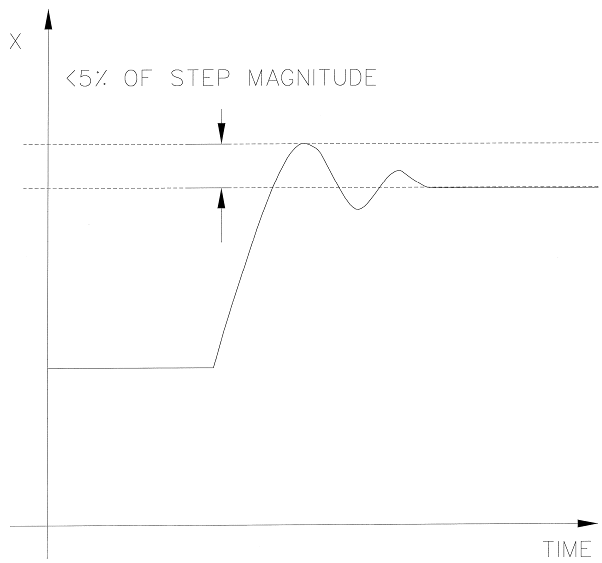

Figure 1. A 0.7 Critically Damped System

Table 7 – Step Response Scoring (After governor has been adjusted)	
Observations (Criteria)	**Adjustment to Condition Index Score**
Off-line speed stability < 0.1 Hertz. Response to speed step correlates with computer simulation or is 0.7 critically damped.	No Change
Off-line speed stability ≥ 0.1 and < 0.2 Hertz. Response to speed step is acceptable, but does correlate closely with computer simulation or is not 0.7 critically damped.	Subtract 0.5
Adjustment has no effect on governor response and unable to adjust governor to prepare for step response test or obtain a 0.7 critically damped response to speed step, or dead time and friction prevent an acceptable response.	Subtract 1.0

Test T2.3: Physical Inspection

The disassembly and physical inspection of the components of the governor can verify findings of other tests and determine if the governor can be restored or is a candidate for replacement. The type of governor will determine the course of action.

Mechanical Governors

The dashpot should be removed and checked for leakage by closing the needle and bypass and pushing the small dashpot plunger down as far as it can go and timing how long it takes to re-center. It should take at least 50 seconds to travel 0.125 inch. If the travel is faster than that, the dashpot requires repairs or replacement. The linkage pins and links should be checked for wear or binding. The main valve should be removed and inspected for signs of wear, chatter, or binding. Make sure the plunger moves freely in its bushing. Remove the plungers from the distributing valve and check condition of seats and piston rings. Remove the pilot valve and check for signs of binding and wear. Check the ball-head for broken springs, and that fly weights move freely.

Digital and Analog Governors

These governors have much fewer mechanical and hydraulic parts to be inspected. Mechanical inspection generally will be limited to the hydraulic governor head, which is usually comprised of a proportional valve and other associated solenoid control valves. The functions that had been performed by the ball-head, pilot valve, restoring cable, dashpot, and associated linkages are now accomplished by a programmable logic controller (PLC). Unit speed and gate position information is input electronically to the PLC instead of by mechanical means. Depending on the model, the proportional valves and other related control valves that are present may be "off-the-shelf" items which were purchased by the manufacturer and then assembled in a complete governor system. Any complete disassembly or maintenance of these valves should be done only after consulting the manufacturer's manual or other factory information. Before turning off power to the governor, check that solenoids are picking up and moving the spool when energized. If not, remove the control valve end caps and determine if the spool moves freely. Inspect all accessible valve and pipe fittings for leakage. Trouble-shooting flow charts should be available from the manufacturer, and may help pin-point problems before resorting to disassembly. Once the problem has been identified, replacement of parts may be the best course of action instead of repair, if the parts are readily available.

Table 8 – Physical Inspection

Observations (Criteria)	Adjustment to Condition Index Score
Damaged parts found and replaced with new parts. Governor response improved.	Add 1.0
No damaged components found.	No Change
Damaged parts found. New parts not available.	Subtract 1.0

Test T2.4: Other Specialized Diagnostic Tests

Additional tests may be applied to evaluate specific governor problems. Some of these diagnostic tests may be considered to be of an investigative research nature. When conclusive results from other diagnostic tests are available, they may be used to make an appropriate adjustment to the Governor Condition Index.

E3.14 GOVERNOR CONDITION-BASED ALTERNATIVES

The Governor Condition Index – either modified by Tier 2 tests or not – may be sufficient for decision-making regarding governor alternatives. The Condition Index is also suitable for use in a risk-based economic analysis model. Where it is desired to consider alternatives based solely on governor condition, the Governor Condition Index may be directly applied to the Governor Condition-Based Alternatives table (Table 9).

Table 9 – Governor Condition-Based Alternatives

Governor Condition Index	Suggested Course of Action
≥ 7.0 and ≤ 10 (Good)	Continue O & M without restriction. Repeat condition assessment as needed.
≥ 3.0 and < 7 (Fair)	Continue operation but reevaluate O & M practices. Consider using appropriate Tier 2 tests. Repeat condition assessment process as needed.
≥0 and < 3.0 (Poor)	Immediate evaluation including additional Tier 2 testing. Consultation with experts. Adjust O & M as prudent. Begin replacement/rehabilitation process.

GOVERNOR
TIER 1 CONDITION ASSESSMENT SUMMARY

Date: ________________________ Location: ____

Gov. Identifier: _________________ Gov. Manufacturer: _______________________________

Yr. Manufactured: ______________________ Yr. Rehabilitated: _________________________

Gov. Control System: ❑Mechanical ❑Analog ❑Digital

Tier 1 Governor Condition Summary *(For instructions on indicator scoring, please refer to condition assessment guide)*				
No.	**Condition Indicator**	**Score ×**	**Weighting Factor =**	**Total Score**
1	Age *(Score must be 1, 2, or 3)*		0.17	
2	Operation & Maintenance History *(Score must be 0, 1, 2, or 3)*		1.17	
3	Availability of Spare Parts *(Score must be 0, 1, 2, or 3)*		0.83	
4	Performance *(Score must be 1, 2, or 3)*		1.17	
Tier 1 Governor Condition Index (Sum of individual Total Scores) *(Condition Index should be between 0 and 10)*				

Tier 1 Data Quality Indicator *(Value must be 0, 4, 7, or 10)*	

Evaluator: ___________________________ Technical Review: ___________________________

Management Review: _________________ Copies to: __________________________________

(Attach supporting documentation.)

Governor Condition-Based Alternatives	
Governor Condition Index	**Suggested Course of Action**
≥ 7.0 and ≤ 10 (Good)	Continue O & M without restriction. Repeat condition assessment as needed.
≥ 3.0 and < 7 (Fair)	Continue operation but reevaluate O & M practices. Consider using appropriate Tier 2 tests. Repeat condition assessment process as needed.
≥ 0 and < 3.0 (Poor)	Immediate evaluation including additional Tier 2 testing. Consultation with experts. Adjust O & M as prudent. Begin replacement/rehabilitation process.

GOVERNOR
TIER 2 CONDITION ASSESSMENT SUMMARY

Date: ________________________ Location: ____

Gov. Identifier: _________________ Gov. Manufacturer: _______________________________

Yr. Manufactured: ______________________ Yr. Rehabilitated: _________________________

Gov. Control System: ❑Mechanical ❑Analog ❑Digital

Tier 2 Governor Condition Summary		
No.	**Tier 2 Test**	**Adjustment to Tier 1 Condition Index**
T2.1	Leakage Test	
T2.2	Step Response Test	
T2.3	Physical Inspection	
T2.4	Other Specialized Diagnostic Tests	
Tier 2 Adjustments to Governor Condition Index (Sum of individual Adjustments)		

Tier 2 Data Quality Indicator *(Value must be 0, 4, 7, or 10)*	

To calculate the Net Governor Condition Index *(Value should be between 0 and 10)*, subtract the Tier 2 Adjustments from the Tier 1 Governor Condition Index:

Tier 1 Governor Condition Index __________

minus **Tier 2 Governor Adjustments** __________ = ________________

Net Governor Condition Index

Evaluator: __________________________ Technical Review: __________________________

Management Review: _________________ Copies to: _________________________________

(Attach supporting documentation.)